INTERNATIONAL AIR TRANSPORT ASSOCIATION

5TH MEETING - FLIGHT SIMULATOR TECHNICAL SUB-COMMITTEE

SEATTLE, MAY 15th-19th, 1980

Agenda Item 7: Visual Systems

DISPLAYS - HOW MANY AND WHERE?

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SUMMARY

Computer Generated Imagery offers to flight simulation the capability of out-of-the-window scenes covering a large field of view. This large field of view is provided by a mosaic of several display channels. How many channels are required and where the displays should be placed involves an analysis of the training requirements. This paper describes methods MDEC has employed in performing this analysis. MDEC has now developed some useful tools for assisting visual customers in the difficult task of deciding on display placements. Also identified are some specific criteria that they find helpful in making these decisions objective ones. In this current era of multiple display visuals, it is hoped that both of these will produce equipment more useful for training.

1. INTRODUCTION

Computer Generated Imagery (CGI) has brought to flight simulation the flexibility to generate true perspective pictures from any viewpoint in space. Figure 1 shows the process in diagram form. Scene elements are stored in a ground base (X Y Z) coordinate reference system. The observer is located at some X' Y' Z' position in this reference system, and his line of sight has a particular orientation in roll, pitch and heading. His position determines his perspective (or-how each scene element appears), and his line of sight orientation (together with CRT size) determines his field of view (or-which scene elements appear). Setting these six variables plus the two constants for CRT size permits the CGI system to perform the translations and rotations transformations which map the scene elements on the CRT. The physical size of the CRT thus becomes the limiting factor for the field of view which can be displayed with a single CRT or channel.

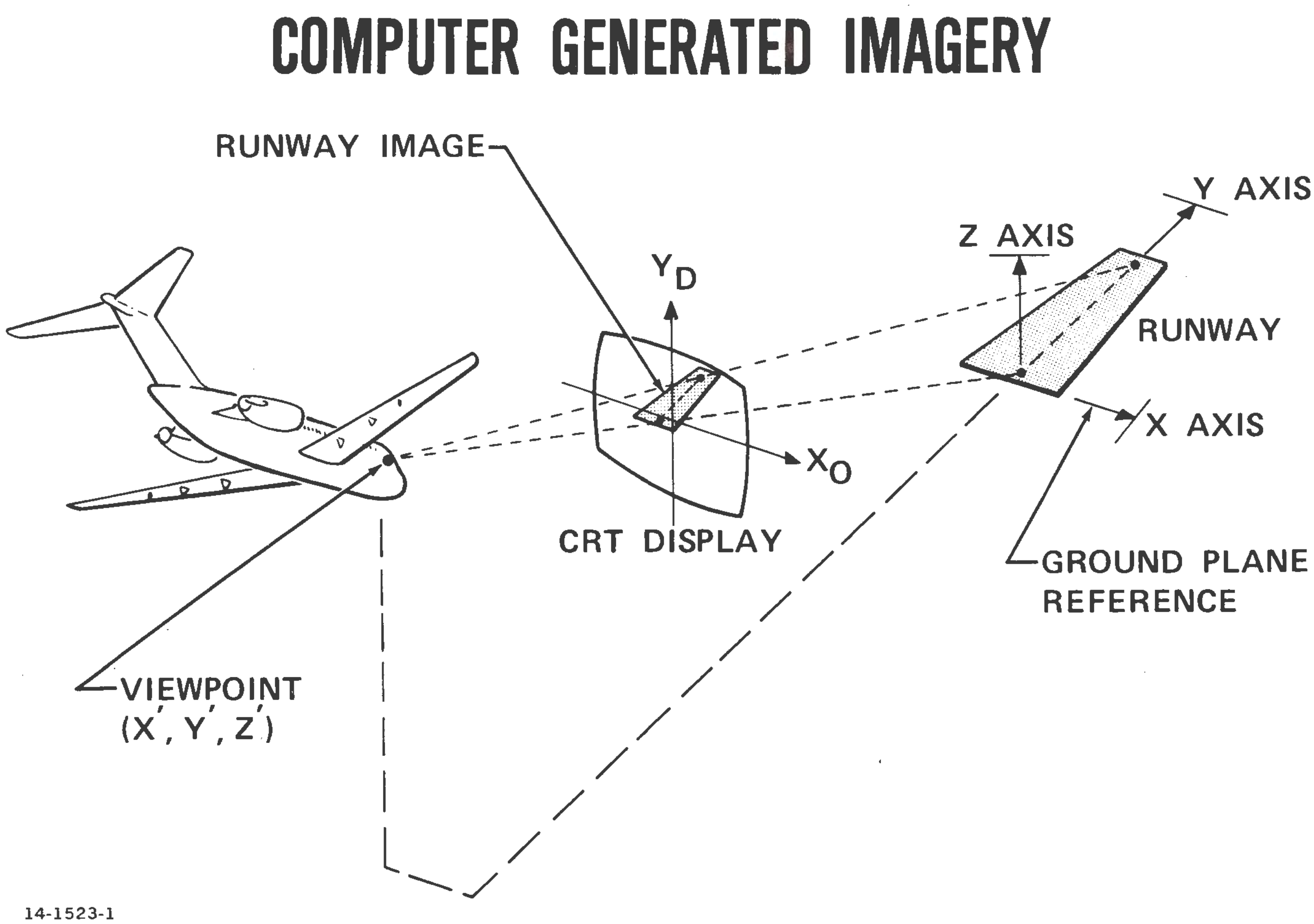


Figure 1.

Since CGI has multichannel capability, several channels may be used to provide a larger field of view than obtainable with a single CRT. This approach is limited only by the physical constraints of placing the CRT/Electronics/Optics units around the cockpit. The questions which naturally arise are how many channels are required and where each should be positioned. The answer to these questions require an analysis of the training requirements. Since each user normally has unique training requirements, this analysis must be performed for each application. A description of the methods MDEC has used to perform the above analysis is the subject of this paper.

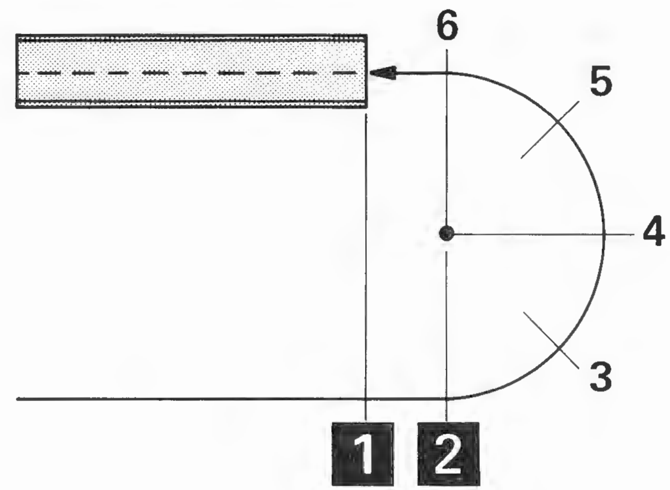
The first four-window VITAL installation was on a DC-8 in 1973. The analysis included taking photographs from the aircraft at various intervals during several circling approaches. For later VITAL installations, a computer program was developed to analytically generate this data on the touchdown point migration. A computer program has also been created to plot the field of view coverage of various VITAL display modules as arranged for specific training requirements. Most recently, a man-in-the-loop flight simulator with a dome type display has been used to develop display placement criteria.

2. ANALYSIS METHODS FOR FIELD OF VIEW REQUIREMENTS

2.1 In-Flight Photos

MDEC first employed multiple channels in 1973 on a DC-8/VITAL II installation. In this application, economics determined that the system would be 4 displays and 3 channels. The unanswered question was the optimum position of these displays to provide circling approach training. In order to obtain data for display placement, in-flight photographs were taken from the pilot's viewpoint during left-hand circling approaches. These photos were taken sequentially at various points during the maneuver. Since a wide angle lens which could cover the front, quarter and side windows was not available, two exposures were made at each position in the pattern and these exposures were later overlaid in a mosaic to simulate a wide angle picture. The 35^{o} X 50^{o} FOV of the camera provided a scale for the result which is shown in Figure 2. Superimposed on this figure are the CRT outlines. The approach was flown by starting a timer when passing abeam the touchdown point on downwind. (This is point 1 on Figure 2.) The portion of the pattern from point 1 to point 2 was flown on instruments

IN-FLIGHT PHOTOGRAPHS



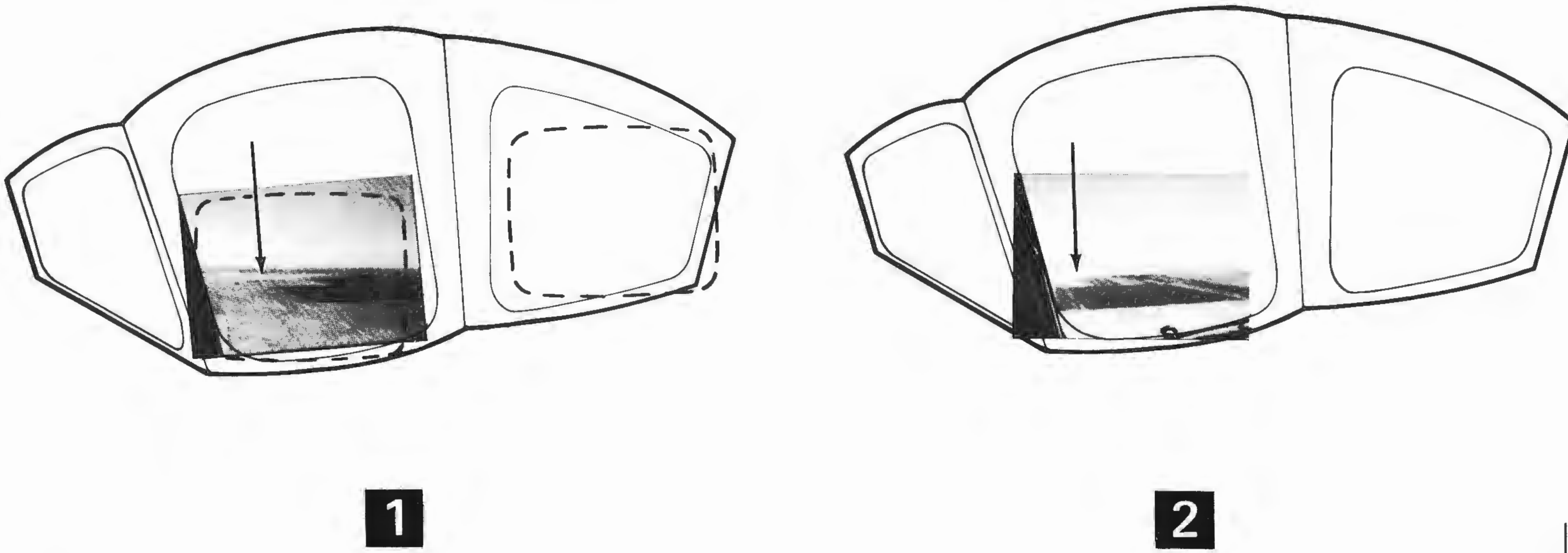


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Figure 2. (Sheet 1 of 3)

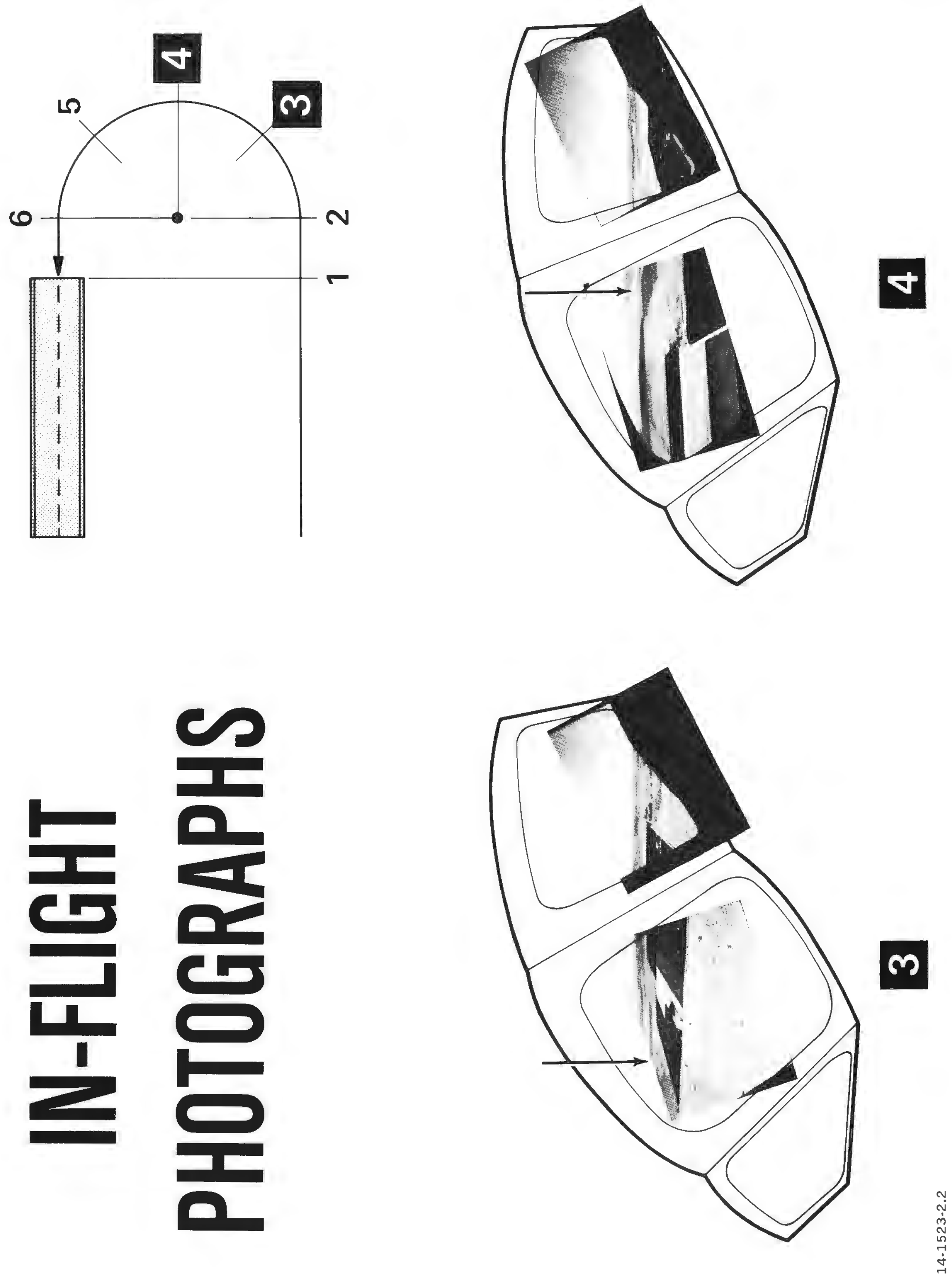
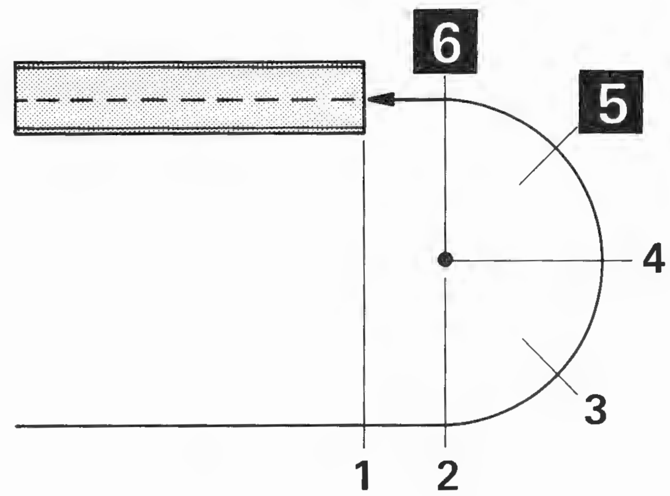
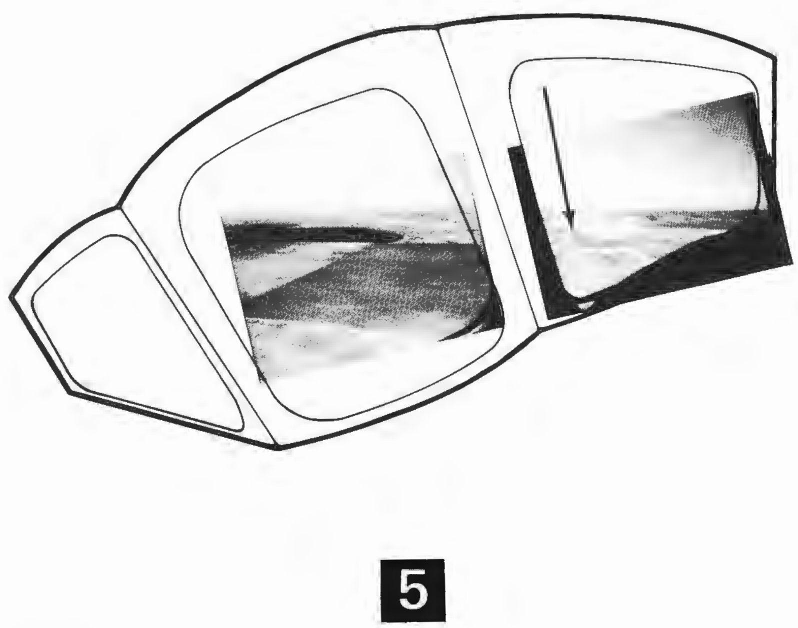


Figure 2. (Sheet 2)

IN-FLIGHT PHOTOGRAPHS





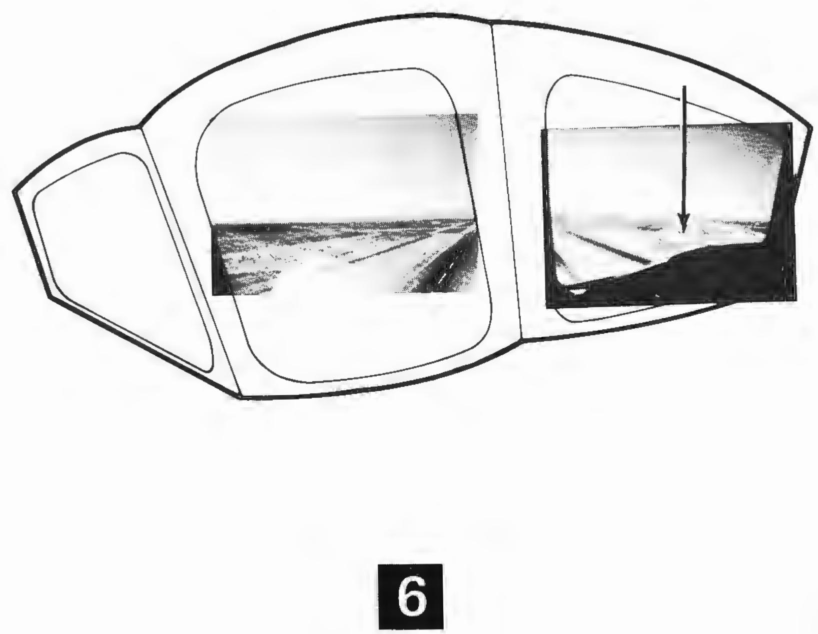


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Figure 2. (Sheet 3)

for 20 seconds. At point 2, a 30° left bank was initiated and visual flight resumed for the remainder of the approach. Three things are noteworthy about Figure 2. First is that the time interval between the first and last exposure at each position does not permit exact registration for adjacent overlays. Second is that the DC-8 windows are quite large in relation to the FOV of the 35 mm camera used. But the photos do provide the desired data -- namely what is in view at various points during the maneuver, and where it appears in relation to the aircraft references.

The third observation is that two displays do not provide sufficient field of view for this maneuver. One critical point is at the 90° abeam position where the timer must be started with visual cues. The second critical area is the last 30° of the turn on to runway heading. It is essential that the runway remain in view during this period to prevent under or over shooting the centerline. Since this represents a span of 60° (90°-30°) and a single CRT provides only 44°, it is apparent that tradeoffs had to be made. The tradeoff finally made was to favor the abeam position in display placement and to display slightly more than 44° of information on each CRT. This was done in order to minimize the time the runway was out of view between the two displays on the turn to final.

2.2 Computer Aided Analysis

The key information provided by the flight test photographs was the migration of the touchdown point. This realization resulted in an effort to create the same information analytically from properly formulated equations. It was felt that assignment of the solution of these equations to a computer would result in more economical (and accurate) results. The problem falls into three areas:

1) Mapping the migration of the touchdown point line of sight angles in azimuth and elevation.

2) Mapping the airplane window geometry.

3) Mapping the instantaneous and total field of view of each optical display unit.

TOUCHDOWN POINT AND WINDOW MAPPING EQUATIONS

TOUCHDOWN POINT MIGRATION

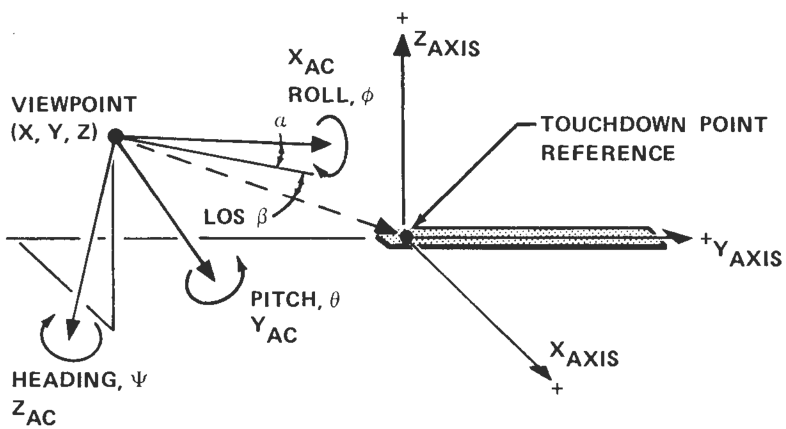

Figure 3.

EQUATIONS

1. $X_{AC} = (-X_{TD})\ SYC\theta \qquad -Y_{TD}CYC\theta \qquad -Z_{TD}S\theta$

2. $Y_{AC} = -X_{TD}\ (C\phi CY + S\phi SYS\theta) + Y_{TD}(C\phi SY - S\phi CYS\theta) + Z_{TD}S\phi C\theta$

3. $Z_{AC} = X_{TD}\ (S\phi CY - C\phi SYS\theta) - Y_{TD}\ (S\phi SY + C\phi CYS\theta) + Z_{TD}C\phi C\theta$

4. AZIMUTH ANGLE $= SIN^{-1} \dfrac{Y_{AC}}{\sqrt{Y_{AC}^2 + X_{AC}^2}}$ (FOR $X_{AC} \geq 0$)

$$= \left[180^{o} - \left|SIN\text{-}1\ Y_{AC} \big/ \sqrt{Y_{AC}^2 + X_{AC}^2}\right|\right]\left[SIGN\ Y_{AC}\right] \text{(FOR } X \leq 0\text{)}$$

5. ELEVATION ANGLE $= SIN^{-1} \dfrac{-Z_{AC}}{\sqrt{X_{AC}^2 + Y_{AC}^2 + Z_{AC}^2}}$ (FOR $|EL| \leq 90^{o}$)

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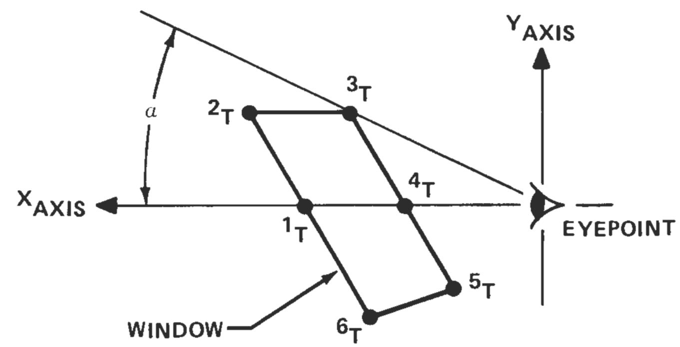
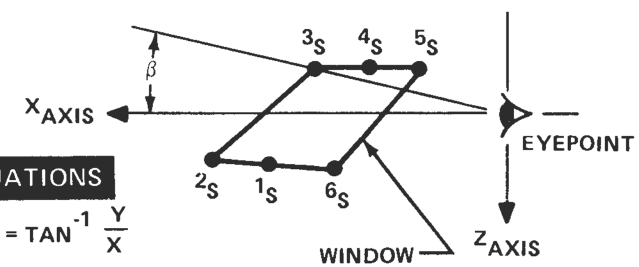
WINDOW GEOMETRY

TOP VIEW



SIDE VIEW



EQUATIONS

1. $\alpha = TAN^{-1} \dfrac{Y}{X}$

2. $\beta = TAN^{-1} \dfrac{-Z}{\sqrt{X^2 + Y^2}}$

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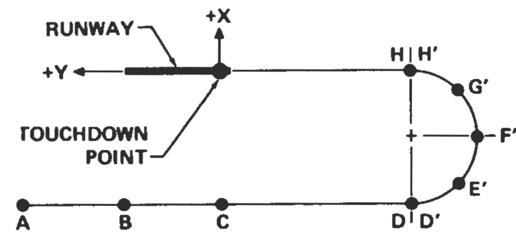
Paper 2

VITAL IV DC-10 (UTA)

PILOT'S VIEW - 1500 FEET CIRCUIT



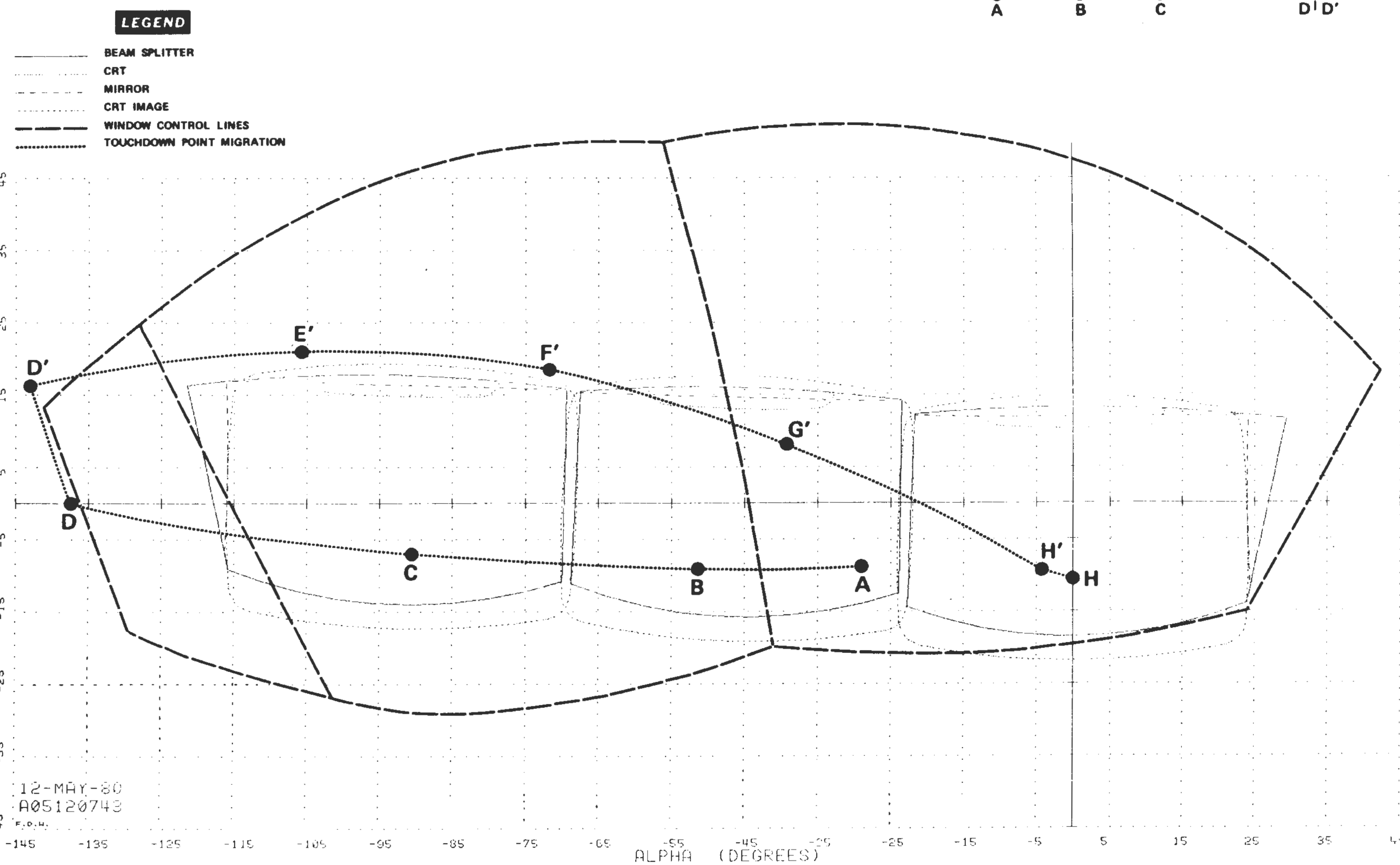


Figure 4.

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Paper 2

The equations for the first two items are quite simple and are readily programmed on a TI-59 calculator. They are shown in Figure 3. The third area is a bit more complex. Involved is the CRT faceplate image which is at approximately 150 feet, the mirror aperture which is located at approximately 50 inches, the beamsplitter aperture which varies in distance from 20 to 50 inches, and the CRT faceplate itself which is approximately 2 feet away from the viewpoint. The equations for these have been programmed in Fortran on a PDP 11/45 with a plotter output. Application of this program to a DC-10 simulator is shown in Figure 4. The 6 display VITAL IV installation is for visual circuit training. Superimposed on this plot are the touchdown point migration and window frame mapping.

Three points are noteworthy about this figure. The first is that three displays provide coverage for the abeam position. The second is that coverage is provided for the last 30° of the turn on to final. The third is that the runway in sight on the entire downwind leg. The third point addresses points A to C on Figure 4 and requires a lower position for the quarter and side displays than would otherwise be selected if concerned only about the turn-on to final.

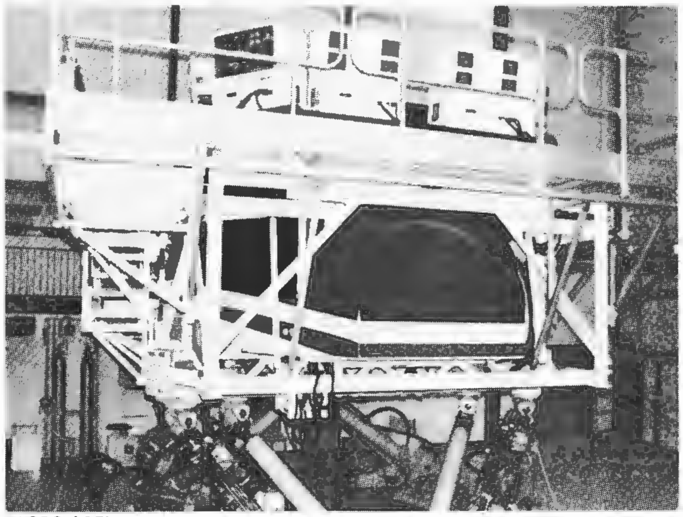
Photos of the resulting mechanical installation and a view of the displays as seen from the pilot's position are shown in Figure 5. This installation validated the computed predictions.

Figure 6 shows a mapping of how the pilot's displays appear to the copilot. Note that only the rear display is viewable and also the "Knothole" appearance of the beamsplitter aperture.

2.3 Dome Type Simulation

The foregoing may give the reader the impression that analysis of field of view requirements has been neatly packaged and labeled and may now be forever relegated to the mystical world of computers for a solution. The following experience is recounted in closing to correct this impression.

The field of view analysis is for a fighter dive bomb delivery. As explained by instructor pilots, the maneuver (Figure 7a) consists of an initial run in to the target at some offset angle. At point "A" the airplane is rolled thru 120° (for



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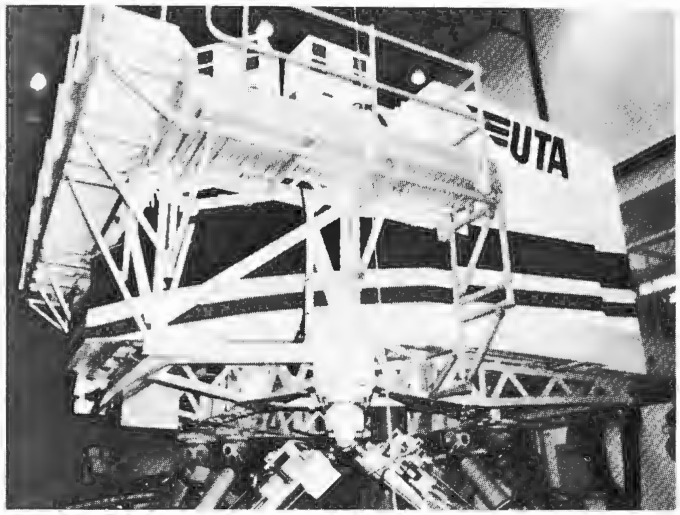

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Figure 5.

VITAL IV DC-10 (UTA)

CO-PILOT'S VIEW OF PILOT'S DISPLAY

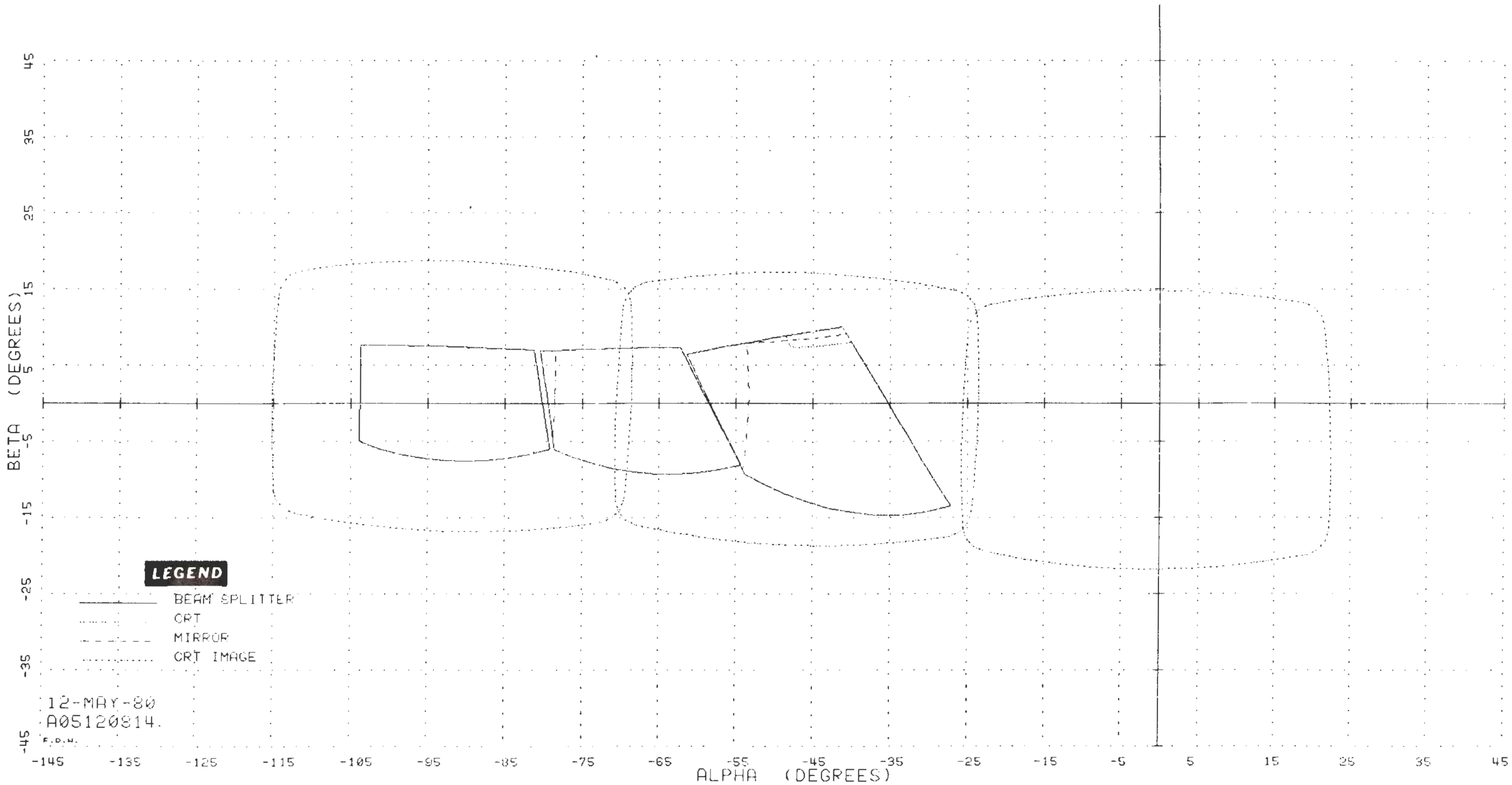

Figure 6.

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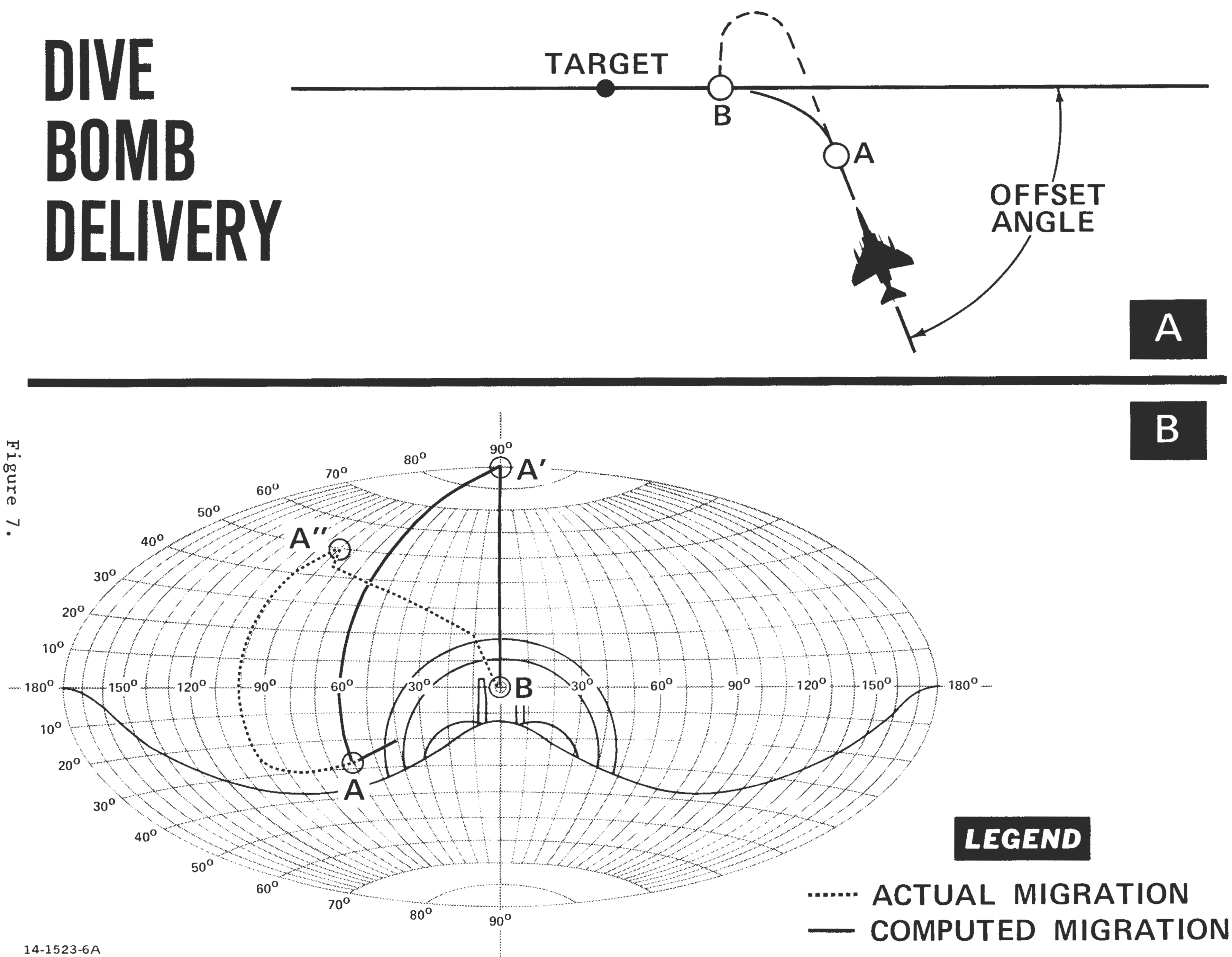
DIVE
BOMB
DELIVERY
TARGET
B
A
OFFSET
ANGLE
A
B
90°
A′
80°
70°
60°
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40°
A″
30°
20°
10°
180°
150°
120°
90°
60°
30°
B
30°
60°
90°
120°
150°
180°
10°
20°
A
30°
40°
50°
60°
70°
80°
90°
LEGEND
ACTUAL MIGRATION
COMPUTED MIGRATION
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Figure 7.

a 30° dive run) and then pitch is increased for a 4 "G" turn in to the target. At point "B" the airplane is rolled level and the final 30° dive run is begun. These parameters were entered into the equations previously discussed and the results plotted in Figure 7b. (Note that this is not like the rectangular plots discussed earlier). Pilot review of this plot of target migration produced the comment that the target did not rise much above the canopy bow during the maneuver in the aircraft. This could be explained only if pitch were applied at point "A" while roll was applied. Since maximum elevation of the target during the maneuver was critical in determining the required field of view, a simulator with a dome type display was used to determine how the maneuver was actually performed. The results are shown by dashed lines in Figure 7b. Note that the target does not rise as high as expected and also that it migrates farther back than predicted by the original analysis.

3. CONCLUSION

To summarize, objective criteria have been applied to analysis of the number and position of the displays required for various visual maneuvers in a flight simulator. The data to be analyzed may be obtained from flight test, from a flight simulator, or by analytical means. Each approach has advantages and disadvantages. The disadvantage of the first two is cost. The disadvantage of the third is that detailed knowledge of the process is required when formulating system algorithms, and experience in the aircraft or a simulator is the most reliable source for this knowledge.